Effect of Extreme Environmental Thermal Cycling On COTS MEMS Pressure Sensor

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Abstract: Motorola's Commercial-Off-The-Shelf (COTS) manifold absolute pressure (MAP, 7 – 110 kPa) sensors were subjected to extreme environmental thermal cycling, beyond the manufacturer's specifications of -40°C to +135°C, to study how robust the package is. The extreme environmental thermal cycling conditions are as follows:

- Total number of cumulative thermal cycles: 23
- Temperature range: -125°C to 90°C
- Ramp rate: 7°C/minute
- Dwell time: 10 minutes

A non-destructive x-ray evaluation technique has been used to image the sensors before and after 15 and 23 thermal cycles. There were no failures observed after 15 thermal cycles. However, our observation shows that sixty seven percent (67%) of the pressure sensors failed due to the opening of wire bonds from 15 to 23 thermal cycles.

Introduction: This pressure sensor has been chosen since it is fabricated using microelectromechanical fabrication technology and the conventional electronic packaging technology. There is no particular mission or project associated with this sensor. Per the manufacturer's specifications this sensor can only be used in engine control systems with a temperature range of -40°C to +135°C.

The feature of the pressure sensors: The specified operating temperature range of the manifold absolute pressure sensors is –40°C to +135°C. The operating characteristics of the sensor are V_{out} Range 0.1 mV min to 4.9 V_{max}. The operating pressure range is 7 kPascals to 110 kPascals. Figure 1 (a and b) show the top and bottom view of the pressure sensor. The manifold absolute pressure sensor is based on a two-chip design with a signal conditioning integrated circuit, which is trimmed to provide the desired calibration. The output is an analog voltage and to Manifold Absolute Pressure. The purpose of these sensors is for engine control systems.

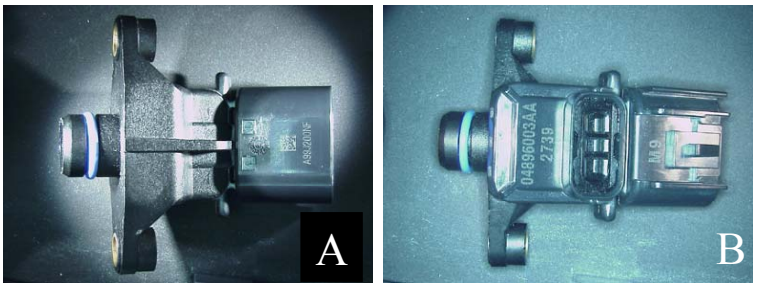

Figure 1: Optical photographs of Motorola's pressure sensor (a) top view and (b) bottom view.

Thermal Cycling Tests: A thermal cycling chamber was used to assess how robust the pressure was in a temperature range of –125°C to +90°C. This chamber has the capability

to perform thermal cycling in a temperature range of –196°C to +200°C. After optical inspection (Figure 1) of the six pressure sensors they were loaded into the chamber for thermal cycling. We prevented condensation by bringing the hardware to a warm temperature before opening the chamber. Figure 2 shows x-ray imaging of the pressure sensor and the wirebonds in the sensor regime performed at 15 thermal cycles from -125°C to +90°C, shown in the thermal profile provided by Figure 3.

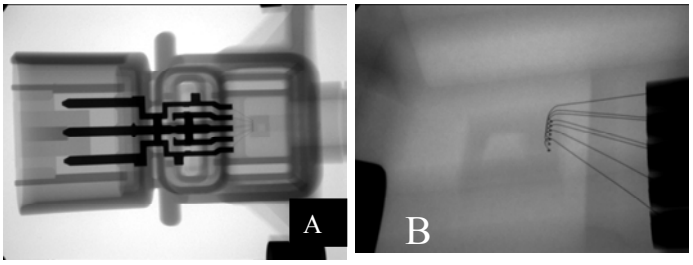

Figure2: X-ray imaging of Motorola's (a) complete pressure sensor and (b) wirebonds in the sensor region where there is a bulk micromachined silicon membrane (sensor 2). This is before thermal cycling.

Figure 4 shows the x-ray imaging of the sensor after 15 thermal cycles. There were no failures observed in the sensor or wirebond integrity. We then performed 8 more thermal cycles. As a result of the additional cycling, several of the wirebonds in pressure sensor number 2 were open. This can be seen vividly in the x-ray image of Figure 5. This indicates that the pressure sensors do fail after 15 thermal cycles, however, we do not know where between the 15th and 23rd cycles the failure took place. We have also confirmed similiar failures with sensors 3, 4, and 6 as shown in the x-ray image of Figure 6.

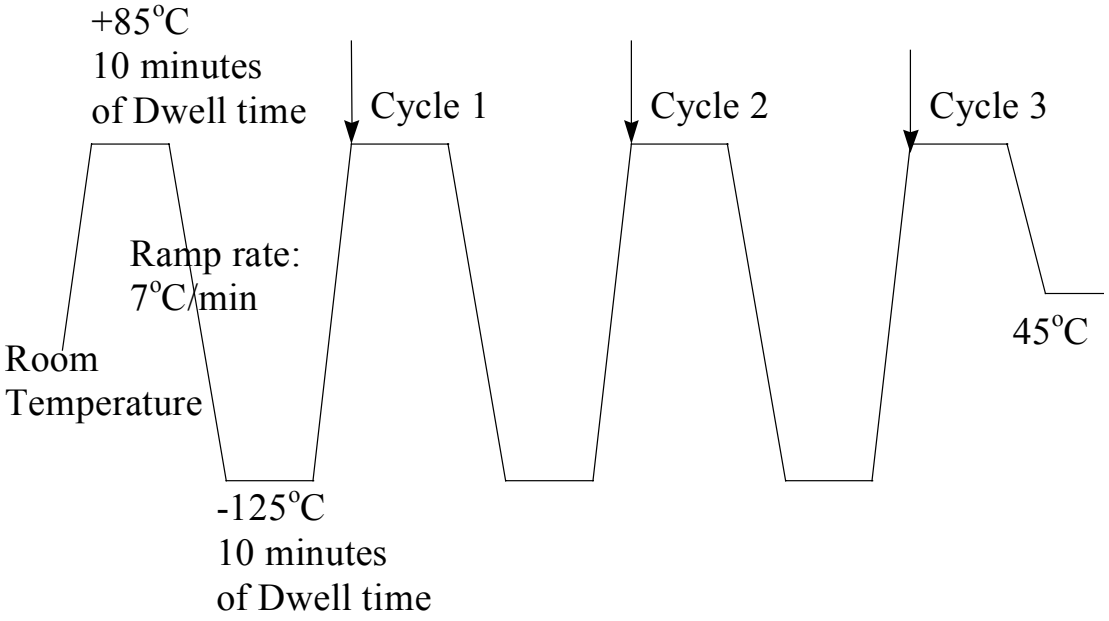

Figure 3: Thermal cycle profile employed for thermal cycling.

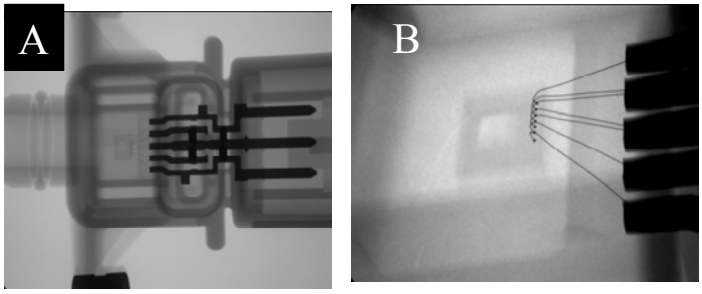

Figure 4: X-ray imaging of Motorola's (a) complete pressure sensor and (b) wirebonds in the sensor region where there is a bulk micromachined silicon membrane, after 15 extreme thermal cycles were performed between -125°C to +90°C (sensor 2). The dwell time is 10 minutes and the ramp rate is 7°C/minutes.

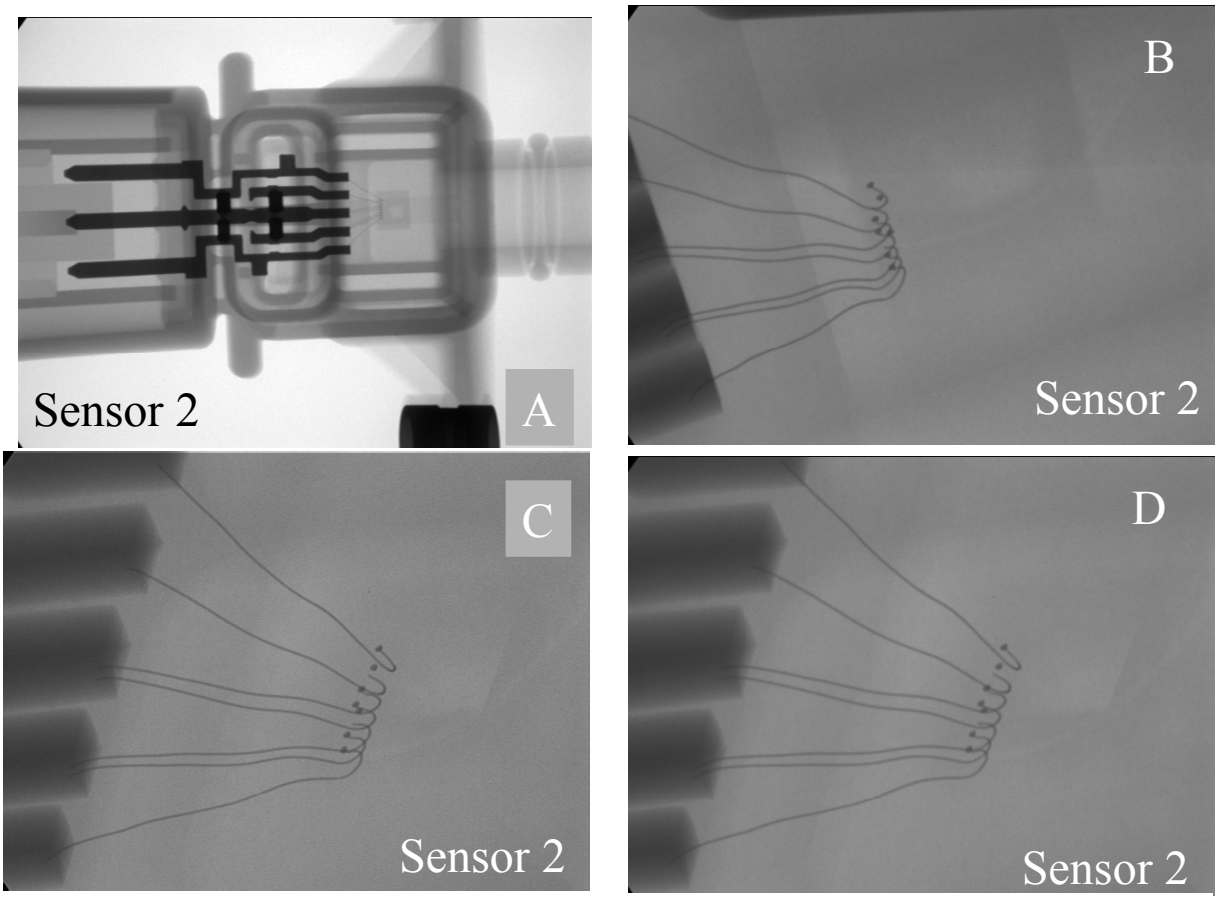

Figure 5: X-ray imaging of the Motorola's (a) complete pressure sensor and (b) wirebonds in the sensor region where there is a bulk micromachined silicon membrane, after 23 extreme thermal cycles performed between -125°C to +90°C (sensor 2). The dwell time is 10 minutes and the ramp rate is 7°C/minute.

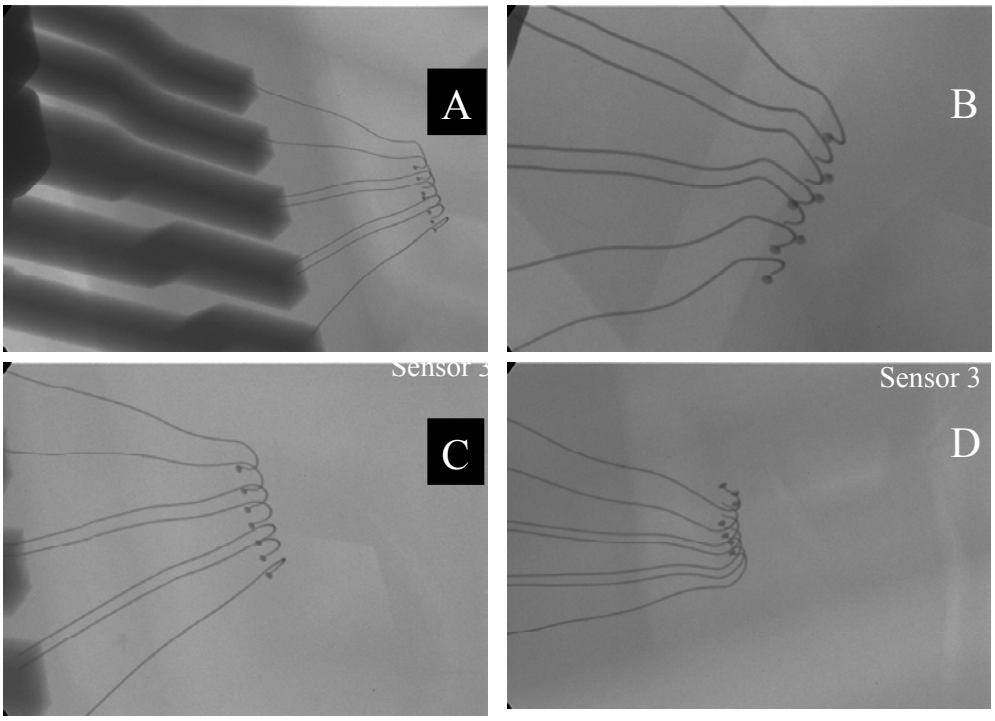

Figure 6: X-ray imaging of the Motorola's (a) complete pressure sensor and (b) wirebonds in the sensor region where there is a bulk micromachined silicon membrane, after 23 extreme thermal cycles performed between -125°C to +90°C (sensor 3, 4 and 6). The dwell time is 10 minutes and the ramp rate is 7°C/minutes.

Summary: Motorola's manifold pressure sensors were subjected to extreme temperature thermal cycling –125^{o}C to +90^{o}C. X-ray images of the pressure sensors where taken before and after 15 and 23 thermal cycles. There was no opening of the wirebonds or failures observed after 15 thermal cycles, however, several wirebonds were open after 23 thermal cycles. Therefore, these COTS pressure sensors were not reliable in the extreme temperature range employed in this test.

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